VISCOUS FLOW OVER SHIP STERNS

by

V. C. Patel

FINAL TECHNICAL REPORT
Sponsored by
Naval Sea Systems Command
General Hydromechanics Research (GHR) Program
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David W. Taylor Naval Ship Research and Development Center
Under Contract N00014-81-K-0200

IIHR Report No. 287

~~Iowa~~ Institute of Hydraulic Research, University of Iowa.
The University of Iowa
Iowa City, Iowa 52242

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: IIHR Report No. 287	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): VISCOUS FLOW OVER SHIP STERNS	5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report October 1980-March 1985
	6. PERFORMING ORG. REPORT NUMBER: IIHR Report No. 287
7. AUTHOR(s): V.C. Patel	8. CONTRACT OR GRANT NUMBER(s): N00014-81-K-0200
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa 52242	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: David W. Taylor Naval Ship Research and Development Center, Bethesda, Maryland 20084	12. REPORT DATE: April 1985
	13. NUMBER OF PAGES: 11
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Office of Naval Research, 536 South Clark Street, Chicago, Illinois 60605	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ship boundary layers, stern flow, wake, measurements, turbulence, calculation methods

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides an overview of the experimental and computational research conducted on the viscous flow over ship sterns during the period October 1980 through March 1985, and summarizes the publications resulting from that research.

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VISCOUS FLOW OVER SHIP STERNS

I. INTRODUCTION

When this research project was initiated in October 1980, it was evident that neither reliable calculation methods nor a comprehensive set of data existed for the description of the complex viscous flow over the stern and in the wake of a ship hull. The 1980 SSPA-ITTC Workshop on Ship Boundary Layers (Larsson, 1981) had indicated that all available methods for the calculation of thin boundary layers broke down, for a variety of reasons, in the stern region. At about the same time, the author (Patel, 1980) reviewed previous experimental investigations in wake flows for the Stanford Conferences on Complex Turbulent Shear Flows and concluded that there was not a single set of reliable and detailed data for three-dimensional stern and wake flows which could be used as a test case for the assessment of calculation methods for such flows. The present investigation was therefore undertaken with three specific objectives:

(1) To develop promising three-dimensional thin boundary-layer calculation methods for application to arbitrary ship hulls and assess their limitations.

(2) To develop a calculation procedure for the flow over the stern and in the wake of a ship.

(3) To conduct a comprehensive, wind-tunnel experiment on a ship double-model to document, in detail, the mean flow and turbulence in the thick stern boundary layer and the near wake.

Many aspects of the research conducted during the course of this project have been reported in a series of publications while others will be discussed at length in publications that are under preparation. A list of publications resulting from sponsorship, or co-sponsorship, of this contract is presented

in the Appendix. For the purposes of the present Final Technical Report, therefore, it suffices to provide an overview of the accomplishments.

II. CALCULATION OF THIN BOUNDARY LAYERS ON SHIP HULLS

The two calculation methods for three-dimensional laminar and turbulent boundary layers developed at Iowa, namely the Crank-Nicolson method of Chang and Patel (1975) and the ADI method of Patel and Choi (1980), have been applied to a variety of test cases, and compared with experimental data, in order to gage their performance, suitability for application to arbitrary ship hulls, and scope for generalization to calculate the flow over the stern and in the near wake. Ref. P5 describes the calculations presented at the EUROVISC Workshop on Three-Dimensional Boundary Layers, Berlin, 1982, using the Crank-Nicolson method. Fourteen participants from several countries presented calculations for one or more of the five test cases prescribed by the organizers. The results of the four test cases calculated by our method agreed very well with the corresponding data and, in regions where some disagreement was noted, most other methods predicted similar trends. Ref. P6 presents calculations made with both the Crank-Nicolson and the ADI methods for the flow over a body of revolution at incidence. Both methods proved to be equally successful in predicting the essential features of this complex flow in regions where the circumferential (girthwise) velocity is unidirectional but only the ADI method, which has the capacity to handle the reversal of transverse velocity, predicted the flow more completely. At this stage, therefore, further development of the Crank-Nicolson scheme was abandoned.

The full capabilities of the ADI scheme was demonstrated quite conclusively by Patel and Baek (1985), who presented extensive laminar, transitional and turbulent boundary-layer calculations corresponding to the detailed experiments conducted at the DFVLR in Germany on a 6:1 spheroid at incidence. This paved the way for the application of the ADI method to ship hulls. The first part of Ref. P8 describes calculations for the 3:1 elliptic body tested by Groves, Belt and Huang (1982) and the Wigley hull tested by Hatano and Hotta (1982). Additional calculations were later performed for the SSPA liner of Larsson (1974) and the HSVA tanker of Hoffmann (1976), which

were used as test cases at the SSPA-ITTC Ship Boundary-Layer Workshop. These will be discussed in detail in Ref. P13.

From the various calculations performed to date, we have concluded that the ADI method is among the most versatile methods available for the calculation of thin boundary layers on three-dimensional bodies. However, like all such methods, it also fails in the thick boundary layer over the stern.

III. THE BOUNDARY LAYER AT THE INTERSECTION OF THE FREE SURFACE WITH THE HULL

The calculation methods discussed above have been applied to only double models, treating the water surface as a plane of symmetry, and ignoring the free-surface waves. As a first step towards studying the influence of waves on the hull boundary layer, the simpler Crank-Nicolson method was used in the second part of Ref. P8 to calculate the boundary layer along the wave using the small-crossflow approximations. These calculations showed that such a simple approach can be used, as a first approximation, to calculate boundary-layer development on a ship hull at nonzero Froude numbers provided the inviscid wave profile is known from experiment or theory. More importantly, the calculations also indicated wave-induced separation at the free surface under the influence of large waves.

Stern (1985) has pursued this problem more rigorously under the sponsorship of the ONR Special Focus Research Program. The ADI method has been adopted to incorporate the most important kinematic and dynamic boundary conditions at the free surface and extensive calculations for a simple geometry indicate that it may soon be possible to extend the ADI method to calculate ship boundary layers at nonzero Froude numbers.

IV. CALCULATION METHOD FOR THE STERN BOUNDARY LAYER AND WAKE

At the beginning of this project it was hoped that the more promising of the two boundary-layer calculation methods will be generalized and extended to treat the thick boundary layer over the stern and the flow in the near wake, and combined with an inviscid-flow method to calculate the region of viscous-inviscid interaction. In preparation for this effort, a thorough review of

the subject of thick boundary layers was conducted and reported in Ref. P2. From this it was apparent that the ADI method offered the best prospect for generalization due to the robustness of the numerical scheme, and its ability to handle arbitrary ship geometries and girthwise flow reversal. Research in this direction has therefore been purused as a thesis topic of a doctoral candidate under the sponsorship of the ONR Special Focus Research Program. The review also indicated that another approach, namely that based on the solution of the partially-parabolic Reynolds-averaged Navier-Stokes equations, should be developed to bring the full power of recent developments in computational fluid dynamics to bear on the problem of stern and wake flows. Some preliminary work was carried under the sole sponsorship of the present contract. With the initiation of the ONR Special Focus Research Program in November 1982, it became possible to devote greater effort to this project and, since then, this aspect of the research has been conducted with joint sponsorship.

Some of the first results obtained with the new partially-parabolic method for axisymmetric flows were reported in Ref. P9. The method was outlined and results for two-dimensional, axisymmetric and some three-dimensional flows (the two elliptic-cross-section bodies tested at the DTNSRDC) were described in the paper presented at the 15th ONR Symposium (Ref. P10). Since then, the pressure-update algorithm has been revised to substantially improve the rate of convergence of the solutions. The latest version of the method is described in detail in Ref. P12.

This method solves the partially-parabolic (or semi-elliptic, or parabolized) Reynolds-averaged Navier-Stokes equations for external flow around arbitrary three-dimensional bodies. Among the main features of the method are the following: Numerically-generated body-fitted coordinates are used to facilitate applications to a wide variety of shapes. The convective-transport equations are discretized using the finite-analytic scheme which employs analytic solutions of the locally-linearized equations. A time-marching algorithm is employed to enable future extensions to be made to handle unsteady and fully-elliptic problems. A two-step global pressure-correction algorithm has been developed to accelerate convergence. The method can be used with large solution domains in order to capture the viscous-

inviscid interaction so that iterative matching between separate viscous-flow and potential-flow solutions is not necessary. For turbulent flows, the well known k-ε model is used, but with a more convenient and realistic treatment of the flow close to solid walls.

The partially-parabolic method is being applied to the Wigley hull and the SSPA liner for which extensive mean-flow and turbulence data are now available. The results will be reported in Ref. P15. Also, calculations have been made for the five axisymmetric bodies (2 tested at Iowa and 3 at the DTNSRDC) on which detailed measurements have been made over the past 15 years. A critical examination of these results, along with those obtained by a variety of other methods, is being conducted in order to make a state-of-the-art review. This will be described in Ref. P16.

In spite of the successes achieved to date, there are a number of aspects of the partially-parabolic method which need to be investigated and improved in order to make it acceptable as a reliable design tool. Of particular concern are the problems of (a) selecting and generating optimal numerical grids for ship forms in which there are abrupt changes in geometry, and (b) assessing the performance of the standard k-ε turbulence model and the wall functions which have been employed. Further experience with the method is required to address these problems. However, it is important to note that the numerical structure of the method has been designed to enable the incorporation of further improvements in these areas, and also to further generalize the method to handle problems such as propeller-hull interaction and even fully-elliptic flows involving longitudinal-flow reversals.

V. EXPERIMENTAL INVESTIGATION OF STERN AND WAKE FLOW

In order to provide a comprehensive data base for the evaluation of calculation methods of the type discussed above, experiments have been conducted on a 10-foot long double-model of the Wigley hull in the large wind tunnel of the Institute. The selection of this simple mathematical form was motivated largely by the fact that it has been studied rather extensively by the wave-resistance community. In fact, it has been selected as one of the test cases for comparisons among the wave-resistance predictions by different methods. As it turned out, it was also a good choice for several other

reasons: (a) the Wigley hull was later selected as one of the four hulls to be investigated at various institutions under the Cooperative Experimental Program of the ITTC Resistance Committee; (b) this, in turn, has led to measurements on double models as well as towing-tank models so that the influence of Reynolds and Froude numbers can be better understood; (c) since boundary-layer theory breaks down along the sharp keel, it provides a rather critical test for more general calculation methods; and (d) due to the termination of the hull at a straight edge, the basic aspects of the evolution of a three-dimensional wake, for which virtually no data exists, can be studied without the added complications of rapid changes in geometry.

As in any three-dimensional flow, the measurements required to describe this flow in adequate detail are enormous and time-consuming. In the present case, surface pressures were measured by means of closely-spaced taps. The three components of mean velocity were measured by a five-hole pitot probe at 14 longitudinal stations, from midships to a distance of 0.8 ship lengths downstream of the stern, along 6 waterlines. The measurement of all six components of the Reynolds-stress tensor at all of these stations presented additional difficulties. A new method for the analysis of the signals from a triple-sensor hot-wire probe to obtain the mean-velocity components and the Reynolds stresses was developed after considerable experimentation. This is described in Ref. P4. The hot-wire measurements are nearing completion and will be described in detail in a doctroal dissertation (Ref. P13) and also presented at a forthcoming symposium (Ref. P14).

VI. RELATED ACTIVITIES

Travel support provided by this contract made it possible for the author to attend several of the meetings of the Resistance Committees of the 16th, 17th and 18th ITTC. The author was responsible for reviews of research in the general area of viscous resistance. His contributions are contained in Refs. P1 and P11.

This contract also provided partial support for Professor K. Mori of Hiroshima University, Hiroshima, Japan, during the period September 1981 - September 1982, and Professor A. Prabhu of the Indian Institute of Science, Bangalore, India, during the period August 1980 - June 1982. Professor Mori's

contributions are contained in Ref. P7. Professor Prabhu made significant contributions to our experimental program (Ref. P4) and also made a detailed asymptotic analysis of the near wake for two-dimensional, axisymmetric, and infinite-sweep geometries (Ref. P3). Other long-term visitors to the Institute during the term of this contract have included Dr. P.A. Krogstad of SINTEF, Trondheim, Norway (July 1981 - June 1982), Dr. V. Truong of ETH, Laussane, Switzerland (April 1982 - March 1983), and Professor M. Ikehata of the Yokohama National University, Yokohama, Japan (June 1983 - November 1983). Although they were not supported by funds from this contract, they also made many valuable contributions to this research project.

VII. CONCLUDING REMARKS

As evidenced by the publications listed in the Appendix, many different aspects of the viscous flow over ship hulls have been addressed under the sponsorship and co-sponsorship of this contract. Among the most significant accomplishments of the project are the following:

(1) The ADI method for the calculation of thin boundary layers has been generalized and tested so that it can be used for practical hull forms.

(2) A powerful new method, based on the solution of the partially-parabolic Reynolds-averaged Navier-Stokes equations, has been developed to calculate the complex turbulent flow over the stern and in the near wake.

(3) Detailed mean-flow and turbulence measurements have been made over the stern and in the wake of a double Wigley model to guide the development of calculation methods and serve as a test case for such methods.

ACKNOWLEDGEMENTS

The bulk of the research summarized in this report was supported by the General Hydromechanics Research Program of the Naval Sea Systems Command, technically administered by the David W. Taylor Naval Ship Research and Development Center, under Contract N00014-81-K-0200, titled "Viscous Flow over Ship Sterns", during the period October 1980 through March 1985. As noted in the text, the level of effort in some aspects of the research was greatly enhanced through joint sponsorship by the Office of Naval Research Special Focus Research Program in Ship Hydrodynamics, Contract N00014-83-K-0136, which was initiated in November 1982. In addition to the investigators involved in the publications listed in the Appendix, the author is indebted to the members of the 16th and 17th ITTC Resistance Committees for many valuable discussions, and to Mr. J. McCarthy and Dr. T.T. Huang of the DTNSRDC for providing critical inputs into the conduct of this research.

REFERENCES

Chang, K.C. and Patel, V.C. (1975), "Calculation of Three-Dimensional Boundary Layers on Ship Forms", Iowa Institute of Hydraulic Research, IIHR Report No. 178.

Groves, N.C., Belt, G.S. and Huang, T.T. (1982), "Stern Boundary Layer Flow on a Three-Dimensional Body of 3:1 Elliptic Cross-Section", DTNSRDC Report 82/022.

Hatano, S. and Hotta, T. (1982), "Turbulence Measurements in the Thick Boundary Layer and Near Wake of a Three-Dimensional Body", Hiroshima University, Private Communication.

Hoffmann, H.P. (1976), "Untersuchung der 3-Dimensionalen, Turbulenten Grenzschicht an einem Schiffdoppelmodell im Windkanal", Inst. Schiffbau, Uni. Hamburg, Report 343.

Larsson, L. (1974), "Boundary Layers of Ships. Part III: An Experimental Investigation of the Turbulent Boundary Layer on a Ship Model", SSPA, Goteborg, Report No. 46.

Larsson, L. (Ed.) (1981), "Proceedings of the SSPA-ITTC Workshop on Ship Boundary Layers - 1980", Swedish Maritime Research Center, SSPA, Report No. 90.

Patel, V.C. (1980), "Ship Wakes: An Overview of Experimental Data", Proc. 1980-81 AFOSR-HTTM-STANFORD Conferences, Vol. I, pp. 552-553, 1982.

Patel, V.C. and Baek, J.H. (1985), "Boundary Layers and Separation on a Spheroid at Incidence", AIAA Journal, Vol. 23, pp. 55-63.

Patel, V.C. and Choi, D.H. (1980), "Calculation of Three-Dimensional Laminar and Turbulent Boundary layers on Bodies of Revolution at Incidence", Turbulent Shear Flow II, Springer-Verlag, pp. 199-217.

Stern, F. (1985), "Effects of Waves on the Boundary Layer of a Surface-Piercing Body", Iowa Institute of Hydraulic Research, IIHR Report under preparation.

APPENDIX

List of Publications Resulting from Sponsorship or Co-Sponsorship of the Present Contract

P1. V.C. Patel, et al., 1981, Report of the Resistance Committee, Proc. 16th ITTC, Leningrad, USSR, September.

P2. V.C. Patel, 1982, "Some Aspects of Thick Three-Dimensional Boundary Layers", Proc. 14th ONR Sym. Naval Hydrodynamics, Ann Arbor, August.

P3. A. Prabhu and V.C. Patel, 1982, "Analysis of Turbulent Near Wakes", Iowa Institute of Hydraulic Research, IIHR Report No. 253, August.

P4. A. Prabhu, O.P. Sarda, B.R. Ramaprian and C.J. Novak, 1982, "A Method for Making Three-Dimensional Turbulence Measurements using a Triple-Sensor Hot-Wire Probe", Iowa Institute of Hydraulic Research, IIHR Limited Distribution Report No. 94, August.

P5. P.A. Krogstad, J.H. Baek and V.C. Patel, 1982, "Calculation of Three-Dimensional Turbulent Boundary Layers using the Crank-Nicolson Method", A Report on Calculations Presented at the Eurovisc Workshop on 3D Boundary Layers, Berlin, April 1982, Iowa Institute of Hydraulic Research, IIHR Report No. 254, August.

P6. V.C. Patel and J.H. Baek, 1982, "Calculation of Three-Dimensional Boundary Layers on Bodies at Incidence", Iowa Institute of Hydraulic Research, IIHR Report No. 256, September.

P7. K. Mori, 1983, "A. Calculation of Wave Resistance and Sinkage by Rankine Source Method; B. Prediction of 2-D Near Wake Flow by Making Use of Time-Dependent Vorticity Transport Equation; C. Free-Surface Boundary Layer and Necklace Vortex Formation", Iowa Institute of Hydraulic Research, IIHR Report No. 262, May.

P8. V.C. Patel, O.P. Sarda and A. Shahshahan, 1983, "Calculation of Ship Boundary Layers", Proc. 4th Sym. Turbulent Shear Flows", Karlsruhe, West Germany, 12-14 September.

P9. H.C. Chen and V.C. Patel, 1984, "Calculation of Thick Boundary Layers and Wakes of Axisymmetric Bodies", Proc. 5th ASCE-EMD Specialty Conference, Laramie, Wyoming, 1-3 August.

P10. H.C. Chen and V.C. Patel, 1984, "Calculation of Stern Flows by a Time-Marching Solution of the Partially-Parabolic Equations", Proc. 15th ONR Sym. Naval Hydrodynamics, Hamburg, West Germany.

P11. V.C. Patel, et al., 1984, Report of the Resistance Committee, Proc. 17th ITTC, Goteborg, Sweden, September.

P12. H.C. Chen and V.C. Patel, 1985, "Calculation of Trailing-Edge, Stern and Wake Flows by a Time-Marching Solution of the Partially-Parabolic Equations", Iowa Institute of Hydraulic Research, IIHR Report 285, April.

P13.* O.P. Sarda, 1985, "An Experimental and Computational Study of Turbulent Flow over the Stern and in the Wake of the Wigley Hull", Ph.D. Dissertation, The University of Iowa, May.

P14.* O.P. Sarda and V.C. Patel, 1985, "An Experimental Study of Turbulent Flow Past a Ship Stern", Proc. 5th Sym. Turbulent Shear Flow, Cornell University, 7-9 August.

P15.* H.C. Chen and V.C. Patel, 1985, "Numerical Solutions of the Flow Over the Stern and in the Wake of Ship Hulls", Proc. 4th Int. Conf. Numerical Ship Hydrodynamics, Washington, D.C., 24-27 September.

P16.* V.C. Patel and H.C. Chen, 1985, "The Flow Over the Tail and in the Wake of Axisymmetric Bodies: A Review of the State-of-the-Art", Proc. Ship Viscous Flow Colloquium, Osaka, 23-25 October.

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